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-tion of object identity, for example, reading a sign. Individual differences in dark focus range from perhaps 15 D in extremely myopic people to as distant as -4 D in the extremely hyperopic; the more distant the individual's dark focus, the greater the individual's tendency to focus beyond an acuity target to maximize apparent size for the discrimination of detail. Some individuals can be trained more readily than others to control the focal distance of their eyes voluntarily; there is some evidence that such trainability depends in part on the individual's dark focus and that both the selection and training of combat pilots should take such characteristics into account.

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Technical Report
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November 1980

GROUND-REFERENCED VISUAL ORIENTATION
WITH IMAGING DISPLAYS: PHASE III
FINAL REPORT

Stanley N. Roscoe

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BACKGROUND

In September, 1977, the Department of Psychology of the University of Illinois at Urbana-Champaign initiated a three-year sequence of laboratory and field experimentation for the Air Force Office of Scientific Research, with Professor Stanley N. Roscoe as Principal Investigator and Dr. Alfred R. Fregly of AFOSR as Scientific Monitor. This program consisted of a deep penetration into the literature of size-distance perception and oculomotor adjustments; the design, procurement of components, and assembly of an infrared motion photophakometer and both laser and polarized vernier optometer systems for measuring visual accommodation while subjects are making size judgments of objects and afterimages at varying distances; the conduct of experiments; and the reporting of findings.

In September, 1979, Phase II of the program was completed at the University of Illinois, at which time the Principal Investigator retired from that institution and joined the faculty of New Mexico State University. Phase III of the program was supported by a new grant to NMSU, and the various items of optical and photographic equipment procured and developed during Phases I and II were graciously transferred to NMSU by the Psychology Department of the University of Illinois.

With the move to New Mexico the continuity of the program was maintained without serious interruption. Dr. Valerie Gawron, who completed her dissertation research at the University of Illinois during Phase II, joined the Principal Investigator at NMSU as a Post-doctoral Research Associate, and Consultant Robert T. Hennessey continued to provide scientific guidance and support. The program was strengthened by the bailment of a Crane-Cornsweet infrared tracking optometer to NMSU by NASA's Ames Research Center, by the additional consulting services of Robert J. Randle of ARC and Dr. Brian Brown of the Smith-Kettlewell Institute of Visual Sciences of the University of the Pacific, and by the direct involvement of Dr. Kenneth R. Paap of the Psychology Department of NMSU in the experimentation.

PROBLEM

Since the late 1940s my colleagues, students, and I have been studying certain evidently related misperceptions experienced by pilots. Objects such as airport runways appear farther away when projected as real or virtual images than they do when viewed directly. As one consequence of this, pilots making landing approaches tend to come in too high and land long and hard. Pilots searching for "bogies" in air combat exercises vary greatly in their abilities to see dark "specks" against a cloudless sky. Clearly factors are at work not accounted for by our conventional understanding of visual acuity.

Relationships between visual accommodation and visual perceptions have been studied by Robert J. Randle, Robert T. Hennessy, and myself at NASA's Ames Research Center, the University of Illinois, and New Mexico State University. We have established a strong correlation between the apparent, or perceived, size of objects of constant actual angular size and an observer's visual accommodation--the distance to which the eyes are focused. Because pilots flying airplanes by contact visual reference view objects at distances much greater than those normally investigated in laboratory experiments, our discovery of the relationship between perceived size and eye focus for distances well beyond the nominal near limit of optical infinity has revealed an important new direction for basic research.

APPROACH

Our investigations included (1) the collection and review of relevant reports (2) the conduct of experiments, and (3) the integration of experimental findings into an increasingly explicit model of how measurable oculomotor functions affect perception of size and distance and the detection of distant targets in textured and untextured backgrounds. Laboratory and field experiments, involved voluntary and involuntary manipulation and subjective and objective measurement of visual accommodation and its correlation with perceptual responses. This three-year investigation has been documented in the following technical reports and journal articles:

Roscoe, S. N., & Benel, R. A. Is the eye smart or the brain forgiving? (Tech. Rep. Eng Psy-78-1/AFOSR-78-1). Urbana-Champaign, IL: University of Illinois, Department of Psychology, 1978.

Iavecchia, J. H., Iavecchia, H. P., & Roscoe, S. N. The moon illusion: Apparent size and visual accommodation distance (Tech. Rep. Eng Psy-78-4/AFOSR-78-3). Urbana-Champaign, IL: University of Illinois, Department of Psychology, 1978.

Benel, R. A., & Benel, D. C. R. Accommodation in untextured stimulus fields (Tech. Rep. Eng Psy-79-1/AFOSR-79-1). Urbana-Champaign, IL: University of Illinois, Department of Psychology, 1979.

Simonelli, N. M., & Roscoe, S. N. Apparent size and visual accommodation under day and night conditions (Tech. Rep. Eng Psy-79-3/AFOSR-79-3). Urbana-Champaign, IL: University of Illinois, Department of Psychology, 1979.

Roscoe, S. N. Ground-referenced visual orientation with imaging displays: Final report (Tech. Rep. Eng Psy-79-4/AFOSR-79-4). Urbana-Champaign, IL: University of Illinois, Department of Psychology, 1979.

- Benel, R. A. Visual accommodation, the Mandelbaum effect, and apparent size (Tech. Rep. BEL-79-1/AFOSR-79-5). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1979.
- Gawron, V. J. Eye accommodation, personality, and autonomic balance (Tech. Rep. BEL-79-2/AFOSR-79-6). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1979.
- Simonelli, N. M. The dark focus of visual accommodation: Its existence, its measurement, its effects (Tech. Rep. BEL-79-3/AFOSR-79-7). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1979.
- Simonelli, N. M. Polarized vernier optometer (Tech. Rep. BEL-79-4/AFOSR-79-8). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1979.
- Hull, J. C., Gill, R. T., & Roscoe, S. N. Locus of the stimulus to visual accommodation: Where in the world, or where in the eye? (Tech. Rep. BEL-79-5/AFOSR-79-9). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1979.
- Gawron, V. J. Differences among myopes, emmetropes, and hyperopes (Tech. Rep. BEL-80-1/AFOSR-80-1). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1980.
- Gawron, V. J. and Paap, K. R. Effects of task performance on visual accommodation and perceived size (Tech. Rep. BEL-80-2/AFOSR-80-2). Las Cruces, NM: New Mexico State University, Behavioral Engineering Laboratory, 1980.

Additional experimental studies undertaken by graduate students under this program are still in progress with the support of New Mexico State University. Also the following papers based on work done under this program have either been published, submitted for publication, or are in revision or preparation for publication in scientific journals:

- Roscoe, S. N. When day is done and shadows fall, we miss the airport most of all. Human Factors, 1979, 21, 721-731.
- Randle, R. J., Roscoe, S. N., & Petitt, J. Effects of accommodation and magnification on aimpoint estimation in a simulated landing task. Washington, DC: National Aeronautics and Space Administration, Technical Paper NASA-TP-1635, 1980.
- Simonelli, N. M. Polarized vernier optometer. Behavior Research Methods & Instrumentation, 1980, 12(3), 293-296.

Roscoe, S. N. Bigness is in the eye of the beholder. Proceedings of the 7th Psychology in the DoD Symposium. Colorado Springs: USAF Academy, 1980.

Gawron, V. J. Eye accommodation, personality, and autonomic balance, III. Proceedings of the 7th Psychology in the DoD Symposium. Colorado Springs: USAF Academy, 1980.

Gawron, V. J. Differences among myopes, emmetropes, and hyperopes. In revision for American Journal of Optometry and Physiological Optics.

Gawron, V. J. Ocular accommodation, personality, and autonomic balance. In revision for Psychological Bulletin.

Iavecchia, J. H., Iavecchia, H. P., & Roscoe, S. N. The moon illusion revisited. Submitted to Perception and Psychophysics.

Hull, J. C., Gill, R. T., & Roscoe S. N. Locus of the stimulus to visual accommodation: Where in the world, or where in the eye? Submitted to Human Factors.

Roscoe, S. N. Bigness is in the eye of the beholder. In preparation for submission to American Psychologist or Psychological Bulletin.

Gawron, V. J. & Porges, S. W. Performance predicted from baseline physiological functioning. In preparation for Psychophysiology.

Gawron, V. J. & Paap, K. R. Effects of task performance on visual accommodation and perceived size. In preparation for Perception and Psychophysics.

MAJOR FINDINGS

Among the many findings reported in the listed documents, the following stand out as contributing to our understanding of the performances of pilots:

1. Judgments of size, and by inference the distance, of objects in natural outdoor vistas are strongly dependent on the distance to which the eyes are focused ($r \approx 0.9$); the exact functional relationship is confounded by the grossly progressive psychophysical inequality of units of the dioptric scale.

2. Accommodation to natural vistas depends in a complicated way on the dark focus of the individual, the retinal locus and spatial frequency of visible texture, and the sharpness of focus needed for the desired discrimination of object identity, for example, reading a sign.

3. Individual differences in dark focus range from perhaps 15 D in extremely myopic people to as distant as -4 D in the extremely hyperopic; the more distant the individual's dark focus, the greater the individual's tendency to focus beyond an acuity target to maximize apparent size for the discrimination of detail.

4. Some individuals can be trained more readily than others to control the focal distance of their eyes voluntarily; there is some evidence that such trainability depends in part on the individual's dark focus and that both the selection and training of combat pilots should take such characteristics into account.

FUTURE APPLICATIONS

Randle's (1970) demonstration of the possibility of conditioning the accommodation reflex by the application of biofeedback techniques calls for systematic investigation of the trainability of individuals varying in dark focus distances and other oculomotor abilities. Basic data in this area are fragmentary but promising, and effective conditioning paradigms are needed that do not require complex and costly equipment and can be applied by individuals with limited research experience if any. We have had some success using a simple polarized vernier optometer as an aid in accommodation training, and this and other possible techniques need to be investigated.

The focal distance of the eyes can be manipulated either voluntarily, following bioconditioning, or involuntarily, by imposing synthetic textural stimuli of appropriate spatial frequencies at appropriate optical distances on an otherwise untextured stimulus field, such as a cloudless sky. Acuity in resolving distant stimuli is enhanced by focusing at a distance greater than that of the stimulus to be discriminated. It is possible that detection of distant "point" targets, analogous to ACM "bogies," also can be enhanced by inducing accommodation to distances at or "beyond" optical infinity (negative dioptric values) for individuals capable of unusually distant focus.

Each of the so-called anomalous myopias and their associated micropsias is encountered in varying degrees, depending on the individual's dark focus, by pilots flying airplanes, particularly ones with head-up displays. Similar myopic responses and micropsic perceptions occur in airplane simulators with contact visual systems. It was, in fact, our concern with the bias errors in landing with imaging flight displays that stimulated our interest in this line of research in the first place. We found that pilots do learn to compensate partially for such biased perceptions. It may be possible to train individuals to recognize the conditions in which to expect micropsic misperceptions and to compensate for them voluntarily.

REFERENCE

Randle, R. J. Volitional control of visual accommodation. AGARD Proceedings No. 82 on Adaptation and Acclimatization in Aerospace Medicine. Neuilly-sur-Seine, France: North Atlantic Treaty Organization, 1970.

ACKNOWLEDGMENT

Phases I and II of this research program were performed at the University of Illinois at Urbana-Champaign under Contract USAF F49620-77-C-0117. Phase III was performed at New Mexico State University under Grant AFOSR-80-0024. Professor Stanley N. Roscoe was the Principal Investigator, and Dr. Alfred R. Fregly was the Scientific Monitor for the Air Force Office of Scientific Research. Major Robert Eggleston and the late Dr. Shelton MacLeod of the USAF Aerospace Medical Research Laboratory provided additional guidance.

